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by

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This paper deals with the problems associated with maintaining and replacing water supply distribution systems. Statistical models as well as graphic displays have been developed to examine the relationship between water supply infrastructure development and urban land development. A technical economic analysis of the factors influencing the reliability of water distribution system and associated costs for repair and replacement was made.

Not only is the issue of system deterioration an economic problem, but also a public health concern. Distribution system failures increase at an exponential rate and it is only a matter of time until serious public outcrys are heard regarding the quality of water at the tap. Many systems are approaching an age when pipe failure becomes a common problem. Proper management and tracking of delivery system performance can result in not only capital costs savings, but in a safer, higher quality product.

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# REPAIR, REPLACEMENT, AND RENOVATION OF DRINKING WATER SYSTEMS

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## INTRODUCTION

There is growing concern over the apparent decay of America's inrastructure - the vast, vital network of roads, bridges, sewers, water systems, rails and mass-transit systems. The decay is most acute in older industrial cities, but other communities, both large and small, rural and urban, are feeling the strain of clogged highways and capacity limitations of water systems.

The Safe Drinking Water Act mandates that we be concerned with the supply of potable water to the consumer. This implies that we must be concerned with not only acquisition and treatment systems, but water delivery systems as well. Many of the water problems in the mid-80's and beyond will be related to capacity expansion, the requirements of treatment for deteriorating water sources and the location of water supply relative to population growth centers.

We tend to take the benefits of a safe, permanent water supply for granted. Most often we are concerned from a professional and regulatory viewpoint with the treatment function because it represents the barrier between potentially infectious disease from uncertain raw water quality and the water users. However, a frequently overlooked fact in the past, and one that is becoming of increasing concern, is the effect that the water delivery system can have on the quality of water received at the tap. Water quality can significantly deteriorate in the delivery system. Coupled with this is the growing concern over the failure of pipes in the hydraulic network that can further jeopardize public health and increase costs. After drinking water has passed through the treatment plant several mechanisms can introduce bacteria into drinking water:

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- open reservoirs;
- enclosed reservoirs to which chlorine is not added occasionally;
- new construction, which may disturb the existing system;
- main breaks, which may become an increasing problem as distribution systems age;
- cross connections improperly installed, which cause back siphonage and back pressure;
- dead ends in mains, which cause stagnate water; and
- living organisms in mains which protect bacteria, but when disturbed, may release bacteria.

Maintenance of water quality in the distribution system is just as important as ensuring that safe water enters the system initially.

Although water delivery systems are a relatively small part of the urban infrastructure, they constitute the bulk of capital expenditures by a water utility (Clark and Gillean, 1977). Not only does the water utility delivery system represent a large and important portion of the water utility's budget, but it also plays a significant role in community health and can become a determinant of the community's growth path and quality-of-life. Table 1 shows the relative investment in the various drinking water functions.

Table 1. Percentage of Cost by Category

| Item | Support Services | Acquisition | Treatment | Power and Pumping | Transmission and Distribution |
|---|---|---|---|---|---|
| Operating Cost | 31 | 22 | 12 | 16 | 19 |
| Capital Cost | 10 | 13 | 10 | - | 67 |

This paper addresses the issue of repair, replacement and renovation of drinking water systems. The issue is examined both from a public health and economic viewpoint.

## PUBLIC HEALTH CONSIDERATIONS

Deficiencies in the delivery system have allowed disease outbreaks to occur in communities. From 1946 to 1980 the incidence of waterborne disease in the United States due to deficiencies in the delivery system of both private and public utilities has involved 102 outbreaks resulting in 13,438 cases. Thus delivery system failures have accounted for 15% of the outbreaks and 9% of the cases recorded for those years. Table 2 displays these data systems encompassing two separate time periods.

Table 2. Incidence of Waterborne Disease

| | Distribution Deficiency | | All Cases | |
|---|---|---|---|---|
| | Outbreaks | Cases | Outbreaks | Cases |
| 1946 - 1970 | 59 | 4,736 | 356 | 72,358 |
| 1971 - 1980 | 43 | 8,702 | 320 | 78,000 |

Distribution system deficiencies account for the highest percentage of all outbreaks (source not specified) followed by treatment deficiencies. However, interruption of disinfection of groundwater supplies accounts for the bulk of cases with distribution failures ranked fourth (Craun & McCabe, 1979).

## COST AND OPERATIONAL CONSIDERATIONS

Distribution system deficiencies, specifically water main breaks, disrupt service, reduce fire fighting capacity, may damage property, as well as pose a public health threat while incurring substantial repair and replacement costs. When a pipe breaks, the leak has to be located, the pipe excavated, the leak fixed or a section replaced. A section of pipe experiencing a significant number of breaks or leaks, may be replaced entirely with a new pipe (Shamir & Howard, 1979). Other costs not readily quantifiable include loss of consumer confidence, and prestige for the city. In addition, lawsuits are a possibility if contamination can be linked to a specific failure. A pre-requisite for city growth is the ability to organize and provide services. One service of critical importance is to supply water of sufficient quantity and quality to provide for all the needs and wants of its customers, something that cannot be achieved if disruption of service becomes commonplace.

This paper reports on the results of a case study conducted in cooperation with a municipal water utility. The following data were collected for each pipe segment: age; diameter; material type; length; absolute pressure; stability and corrosiveness of soil type; percent of length in various land use categories; numbers of breaks and their associated dates; and original installation cost.

With these data the following evaluations were made: survival analysis; probability of maintenance event; and maintenance event equations.

## SURVIVAL ANALYSIS

A life-expectancy curve was developed for all the pipes based on their age. Five-years-old mains with no maintenance events can expect to have an additional 22.2 years without an event, while 40-year-old mains have 15.6 years, and 75-year-old mains have 2.5 years remaining before experiencing its first break. The longer a pipe exists without experiencing a break, the longer its total life.

## PROBABILITY OF FAILURE

Of the pipes studied, only 21% experienced maintenance events, even after long periods of time. For those that did experience such events, the time between subsequent events became increasingly short. To study this phenomenon, the interarrival time between repair was formulated as an exponential function (Cox and Miller, 1965).

Examination of the data revealed that two underlying mechanisms seemed to be occurring with those pipes that experienced maintenance events. A lag period occurred between the time the pipe was installed and the first maintenance event. The average time to the first repair was 21.5 years. After the first events, the number of events seemed to increase exponentially. Two equations were developed to represent these phenomena. The first to estimate the time to the first repair and the second to estimate the number of events occurring after the first event.

## SUMMARY AND CONCLUSIONS

This paper deals with the problems associated with maintaining and replacing water supply distribution systems. Statistical models as well as graphic displays have been developed to examine the relationship between water supply infrastructure development and urban land development. A technical economic analysis of the factors influencing the reliability of water distribution systems and associated costs for repair and replacement was made.

Not only is the issue of system deterioration an economic problem, but also a public health concern. Distribution system failures increase at an exponential rate. Many systems are approaching an age when pipe failure becomes a common problem. Proper management and tracking of delivery system performance can result in not only capital costs savings, but in a safer, higher quality product.

## REFERENCES


1. Clark, Robert M. and Gillean, James I., Cost of Water Supply and Water Utility Management (Volume II), EPA-15-77-015b, Municipal Environmental Research Laboratory, USEPA, Cincinnati, Ohio, 1977, p. 24.

2. Cox, D. R., and Miller H.D., The Theory of Stochistic Processes, Mathuen and Co., Ltd., 11 Fetter Lane, London, LC4, 1965, p. 155.

3. Craun, Gunther F. and McCabe, Leland J., "Review of the Causes of Waterborne Disease Outbreaks," Journal of the American Water Works Association, Vol. 65, No. 1, January 1973, pp. 74-84.

4. Shamir, Uri and Howard, Cheres, P.D., "An Analytic Approach to Pipe Replacement," Journal of the American Water Works Association, Vol. 71, No. 5, May 1979, pp. 248-259.